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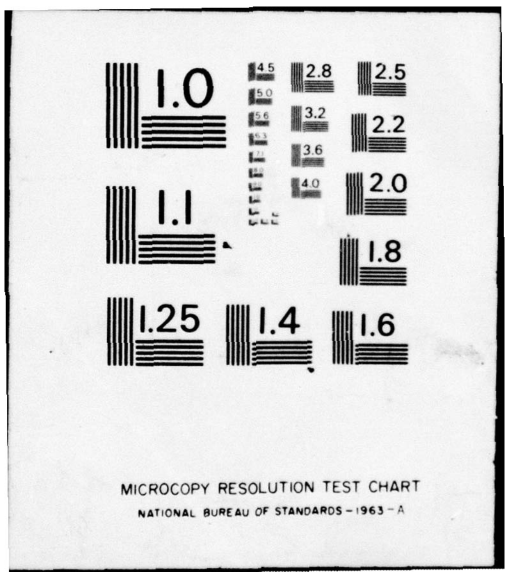
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Planning and execution of an effective noise control program requires definition of the harmful effects of noise to be prevented and the establishment of goals to be achieved. In response to the Noise Control Act of 1972 the US Environmental Protection Agency conducted studies to clarify the cause and effects relationships between the noise environment and various health effects, which were published in a "Criteria Document." Based on these findings environmental noise levels were identified, at or below which the population would be protected against adverse effects on health and welfare; this information was

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CONT

published in the "Levels Document." The rationale for selecting basically one descriptor for characterizing noise environments with respect to their health effects ~~(L_{eq}, L_{dn})~~ and the justification for the levels selected based on hearing conservation and activity interference/annoyance criteria will be discussed. The use of these levels in the overall environmental noise control program and their relationship to industrial/occupational noise exposure limit levels will be explained.

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Criteria for evaluating the harmful effects of noise *

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Introduction

One of the starting points of any noise control program is the characterization of the noise environment, a measure of the noise exposure to indicate the severity of the problem, how much each noise source contributes to the overall noise environment

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*This paper is a condensed version of AMRL-TR-75-40 entitled, "Development of a Uniform Approach to Characterize Noise Impact on People", which was presented at the 46th Annual Scientific Meeting on the Aerospace Medical Association, April 1975, San Francisco, California.

The research reported in this paper was conducted by personnel of the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, and supported in part by the Environmental Protection Agency (EPA) under Interagency Agreement No. EPA-IAG-D4-0376. This paper has been identified by Aerospace Medical Research Laboratory as AMRL-TR-75-43. Further reproduction is authorized to satisfy needs of the US Government.

and how effective any control action is going to be. Unfortunately, it is already at this point that some decisions and value judgments have to be made, which are outside the scientific domain. These judgments have led to disagreements over the past two decades among scientists and various interest groups and have delayed decisions and concerted actions. The problem is not how physically to measure the noise environment. Rather it is how to condense this continuously fluctuating noise level—fluctuating with respect to intensity and frequency composition—into one descriptor characterizing the noise with respect to its effect on man. The questions are obvious: What do we mean by "effects of noise on man"? Effects on hearing? On speech communication? On sleep? On physiological functions? Or do we mean the not too well defined annoyance response of people, where even the response of the same individual to the same noise can change from day to day? This question has to be settled first, so that a measurable goal and valid investment strategy for the noise control program can be stated.

At the 1973 International Congress on Noise as a Public Health Problem [1] a review of methods for the evaluation of noise discussed six possible ways for the direct measurement of noise, 9 measures to calculate the noise of individual events, and 13 measures to evaluate the severity of community exposure to multiple events, the real condition of environmental noise. It is obvious that this situation has not helped the communities, industries, government bodies and lawmakers concerned about noise, has brought disrepute to the scientific disciplines involved and has confused the issues in the courtrooms. In all fairness it must be said that there was good technical justification for most of the measures proposed or used and in many cases the practical differences between the measures were actually small. But in land-use planning or aircraft noise control small differences in the noise evaluation measures and in the limit values used can result in large differences in land areas and millions of dollars in cost. Consequently, all efforts to standardize the noise evaluation measure and a prediction procedure were unsuccessful because of differing viewpoints and lack of agreement on common goals.

In the United States, it took the Noise Control Act of 1972 to overcome the deadlock of this situation.[2] Through this Act, Congress declared a national policy "to promote an environment for all Americans free from noise that jeopardizes their public health and welfare". The Act established the goal to control environmental noise with public health and welfare as evaluation criterion. Among other duties, the Congress directed the Environmental Protection Agency (EPA) to publish:

(a) "The scientific knowledge most useful in indicating the kind and extent of all identifiable effects on the public health or welfare which may be expected from differing quantities and qualities of noise".

(b) "Information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety".

(c) "Implications of identifying and achieving levels of cumulative noise exposure around airports".

In response to these charges, the EPA produced several reports [3,4,5] with the collaboration of Federal Interagency Task Forces, the National Academy of Sciences, scientific, industry and citizen representation. The result had to be a compromise based on the best interpretations and extrapolations of the available knowledge. The following is a brief report on the outcome of these studies.

The descriptor of environmental noise exposure

In relating the complex noise environment of a population to its health and welfare, the definition and characterization of health and welfare by one indicator is just as difficult as the definition of the environment. Health according to the definition of the World Health Organization is not the mere absence of disease but total physiological and psychological well being. Based on this general interpretation of public health, the following three well-proven effects of noise exposure on health, functional capacity and well-being were considered: (a) the effects of noise on hearing, (b) the direct effects of noise on speech

communication, (c) the effects of noise on general well-being as a result of interference with sleep, relaxation, speech communication and other activities.

By singling out these three categories of health effects, the possibility of other effects resulting in direct physical or mental illnesses in small segments of the overall population will not be completely ruled out. However, present epidemiological evidence as well as hypotheses based on animal experiments are not strong enough to support such possibilities for the levels identified here. On the contrary, all available evidence points to the conclusion of a recently published authoritative summary [6] that "if noise control sufficient to protect persons from ear damage and hearing loss were instituted, then it is highly unlikely that the noises of lower level and duration resulting from this effort would directly induce non-auditory disease".

For selecting the most meaningful and practical descriptor from the 10 to 20 available options, the following conditions were agreed upon:

1. The measure should be applicable to the evaluation of noise in all possible exposure conditions over long periods of time. It should allow characterization of the noise environment in fixed locations as well as that of individuals moving from place to place.

2. The measure should correlate well with known effects of noise on individuals and on the public.

3. The measure should be simple, practical, and accurate. In principle, it should be useful for planning and monitoring as well as for enforcement purposes.

4. The required measurement equipment, with standardized characteristics, should be commercially available.

5. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.

6. The measure should be closely related to existing methods currently in use.

Based on these ground rules two decisions were agreed upon:

1. To account for the dependence of human reaction on the frequency content of the noise the A-weighted sound level was selected.

2. To correlate the cumulative long term effects with a single descriptor led to the selection of the long-term average sound level, called equivalent sound level (L_{eq}), as the best descriptor for the magnitude of environmental noise. It is the constant sound level, which in a given situation and over the considered time period, would expose the ear to the same amount of energy as does the actual time varying noise pattern. This concept has been widely used to relate individual and community reaction to aircraft and to other noises.

Consequently, the basic descriptor for environmental noise is:

$$L_{eq} = 10 \log_{10} \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} 10^{L_A(t)/10} \, dt$$

where $t_2 - t_1$ is the time interval over which the levels are evaluated.

This simple concept of the equivalent sound level had to be somewhat refined to account for the fact that the same noise environment is considered more disturbing or annoying during the night than during the day, as revealed by most community response and public opinion surveys. To penalize nighttime noise events commensurate with the severity of disturbance, a weighting factor of 10 dB is applied to all nighttime noises; i.e., nighttime noises are treated as if they were 10 dB noisier than they actually are. The day-night weighted $L_{eq(24)}$ is being called the day-night sound level or L_{dn}:

$$L_{dn} = 10 \log_{10} \frac{1}{24} [(15)(10^{L_d/10}) + (9)(10^{(L_n+10)/10})]$$

with L_d and L_n standing for the daytime and nighttime sound levels respectively.

The advantages of L_{eq} and L_{dn} are best verified by showing that these measures satisfy all six requirements listed above.

The L_{dn} descriptor can be related to and can be used to approximate most previously used statistical descriptions and noise evaluation schemes such as L_{10} or L_{50}, NEF, CNR, NPL, etc.[5] An approximate rule of thumb for the measures used in connection with aircraft noise in the USA is:

$$L_{dn} \simeq \text{CNEL} \simeq \text{NEF} + 35 \simeq \text{CNR} - 35$$

One big advantage of L_{eq} and L_{dn} over most of these other measures is that they can easily be measured and monitored over long time periods. Noise is described as

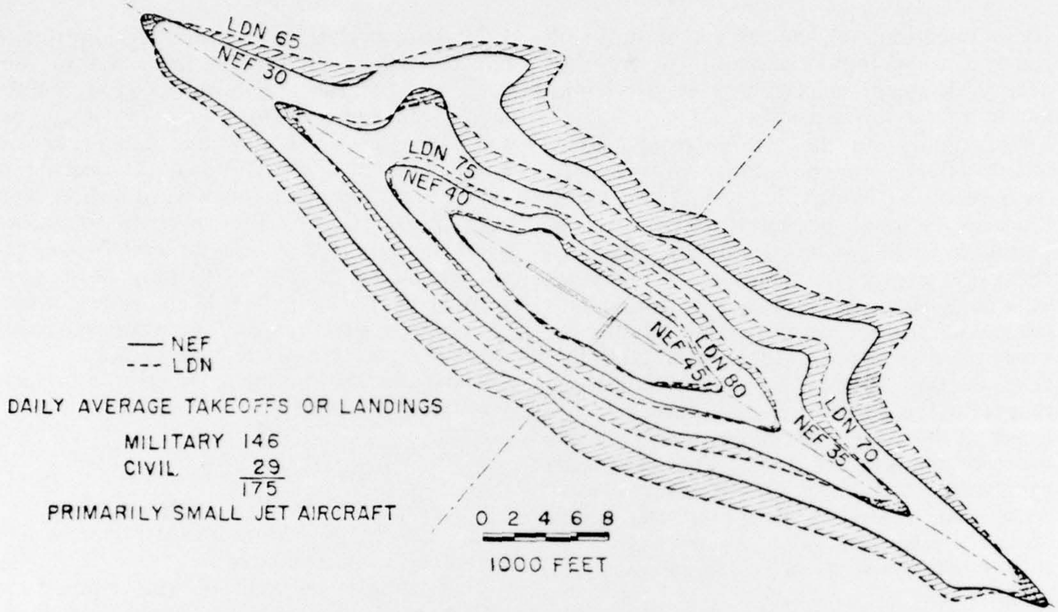

Fig. 1—Examples of NEF (Noise Exposure Forecast) and L_{dn} (day-night average sound level) contours around an airbase.

noise: traffic noise can be compared to aircraft noise, to lawnmower noise and internal noise in factories or residencies. The noise from all sources can be measured and calculated as the total environmental noise to which individuals and the population are exposed. And, after all, it is this total environmental noise exposure that leads to the long-term cumulative effects on public health and welfare. It is this total noise exposure that must be reduced if a noise control program is to be successful.

A comparison of calculated noise contours around an airbase, L_{dn} vs. NEF, is shown in figure 1. In this example the pure tone correction contained in NEF extends the exposure pattern under the flight path only slightly, and the L_{dn} contours, somewhat less affected by atmospheric attenuation, extend the exposure pattern further out to the side of the flight path. Obviously there is a difference in the contours that conceivably can influence aircraft operations and land use planning decisions. However, as the example illustrates, the net differences tend to equalize. In other words, it is not so that the NEF procedure penalizes aircraft noise uniformly in all directions as is frequently assumed. In general these differences can be considered small when compared to the uncertainties and fluctuations in the predicted or observed human response.

Figure 2 illustrates how an individual's

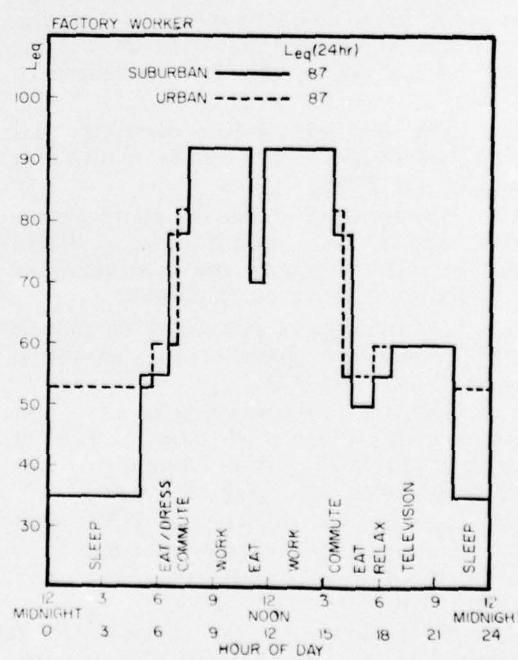

Fig. 2.—Typical individual daily noise exposure pattern for a factory worker. ($L_{eq(24)} \simeq L_{dn} = 87$ dB). (From ref. 5).

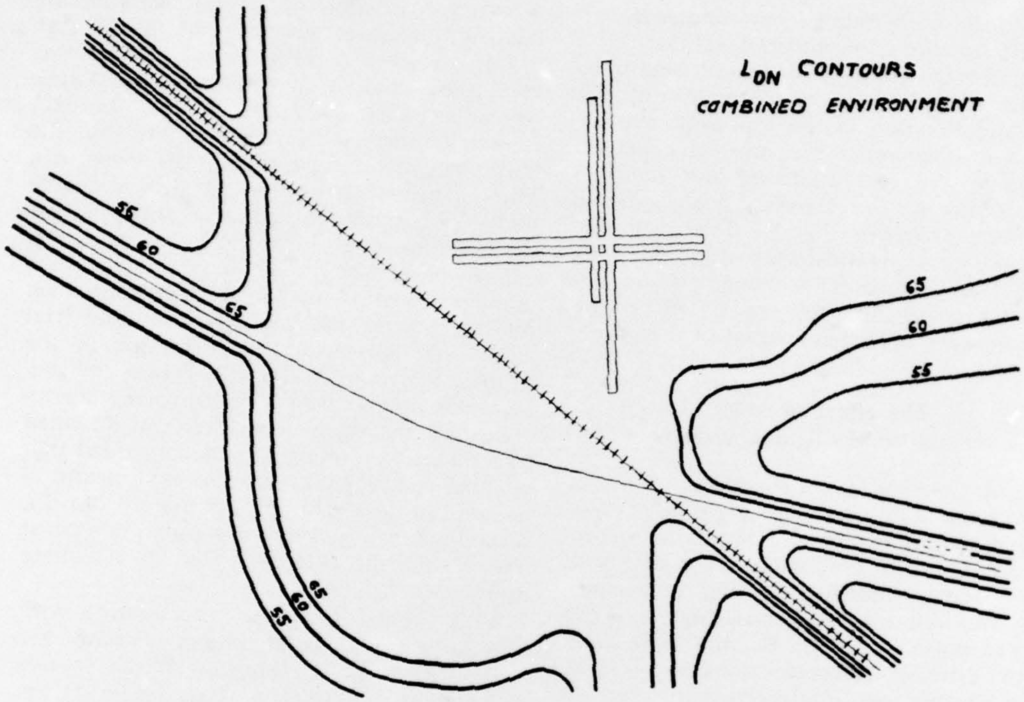

Fig. 3.—Example of combined noise contours in L_{dn} for airport, highway and railroad traffic. (Airport: Total annual operations 15,000, day/night ratio 99:1. Highway traffic: 35,000 daily movements, 3500 during peak hours. 4% trucks. Railroad traffic: 6 freight, 4 passenger trains. All during daytime).

total daily noise exposure can be calculated from his exposures at the various places he visits during his daily living routine.

Figure 3 illustrates how the noise exposure contours from various sources can be combined into total noise exposure contours describing the overall noise exposure of the areas. It is easy to see how this uniform concept applies to all types of noise sources and allows the evaluation of specific noise control or planning measures. It is this type of descriptor and evaluation tool, which any noise control effort needs to set priorities between various measures, to evaluate cost effectiveness and to char- →

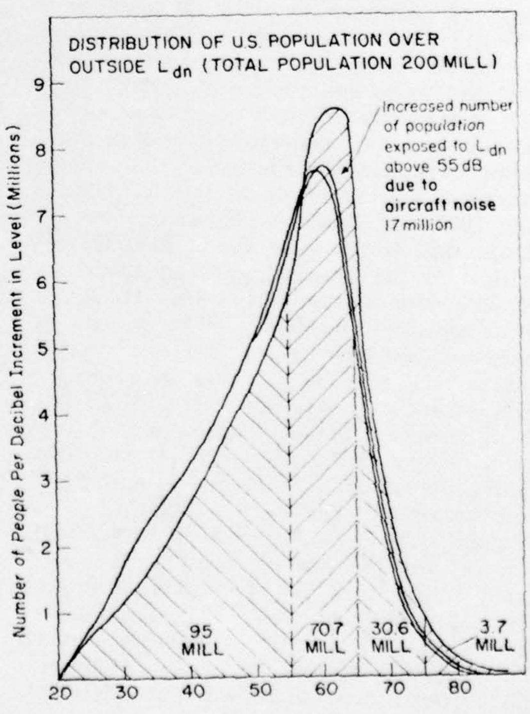

Fig. 4.—Exposure of the US population to environmental (outdoor) noise. The number of people per decibel increment in level is plotted as a function of the outdoor day-night average sound level. The contribution to the distribution curve from freeway traffic and aircraft noise is indicated separately. The number of people exposed to levels above certain limits is approximate. (From Galloway and Eldred[7] and ref. 5).

acterize the noise related environmental impact of specific contemplated actions.

The average outdoor day-night sound levels to which various percentages of the US population are exposed present a practical and illustrative measure in order to determine the magnitude of the national noise problem, to establish goals and to determine progress (Fig. 4).[7] The basic distribution curve is primarily dominated by urban traffic noise. The change in the distribution curve due to aircraft noise and freeway noise is also estimated in the graph.

The effect of noise on public health and welfare

In the course of identifying levels of environmental noise, the attainment and maintenance of which are requisite to protect public health and welfare, the EPA task forces first established as clearly as possible the quantitative knowledge on the effect of noise on health. For the three main health criteria selected, namely noise-induced hearing loss, interference with speech communication and annoyance/complaint responses of individuals as well as communities, this relationship will be briefly reviewed without detailed justification.[4,5]

With respect to noise-induced hearing loss, the definition of "significant effect on hearing" had to be approached differently from the criteria traditionally employed in industrial hearing conservation and compensation. Traditional criteria have used the averaged hearing levels at the frequencies 500, 1000 and 2000 Hz. However, the evidence that frequencies above 2000 Hz are critical to the understanding of speech in life-like situations and that 4000 Hz is the most sensitive frequency with respect to noise-induced hearing loss, led to the selection as criterion for safe exposure: no significant effect on hearing level at 4000 Hz.[5,8] A significant effect on hearing was defined as a change in hearing level of less than 5 dB, the usual level of reproducibility in individuals. (In the past a "handicap" for individuals was usually defined by a 25 dB "fence" for the hearing level at the averaged frequencies 500, 1000 and 2000 Hz). To follow the intent of the Noise Control Act virtually the entire population should be protected against the risk of noise-induced permanent threshold shift (NIPTS). A careful reevaluation of all available industrial noise studies resulted in the risk graph of figure 5. From these data it was concluded that a 40-year noise exposure below an $L_{eq(8)}$ of approximately 73 dBA is satisfactory to protect practically the entire population against a NIPTS of 5 dB. These results from industrial exposures were adjusted by the equal energy rule for the fact that environmental noise exposures can go on for 24 hrs per day and 365 days per year (instead of the 8-hr exposures on 250 workdays per year in the industrial situation). This led to a correction in the exposure level of —6.5 dB. Since environmental noise is usually intermittent, an increase of the equivalent level was justified (+5 dB). In summary, it was concluded that keeping the yearly average of environmental noise $L_{eq(24)}$ less than approximately 70 dBA, should protect the general population against any significant NIPTS with an adequate margin of safety.

With regard to noise interference with human activity, good objective data are available on the masking of speech sounds by intruding noise of various levels. It appeared that 100% sentence intelligibility was necessary for relaxed conversation in a typical living room for all talker-to-listener separation distances, in order to protect speech communication in a private home. This is achieved at an L_{eq} of 45 dB. Allowing for a typical, average sound level reduction between outdoors and indoors of 15 dB this level translates into an outdoor level of no greater than L_{eq} 60 dB for residential areas (Fig. 6). At this outdoor environmental noise level normal conversation can be conducted at distances of up to 2 meters with 95% sentence intelligibility, a situation considered satisfactory in most outdoor activities. Since the day/night average noise level in most areas with such equivalent levels is approximately 3 dB above the equivalent level, the outdoor level that will assure adequate speech communication capability indoors as well as outdoors is an L_{dn} of 63 dB. However, although speech interference is one of the primary interference effects of noise, community response studies over the past 20 years have clearly shown that there are other adverse effects, particularly during nighttime, which lead to annoyance and clearly expressed dissatisfaction with the environment. The

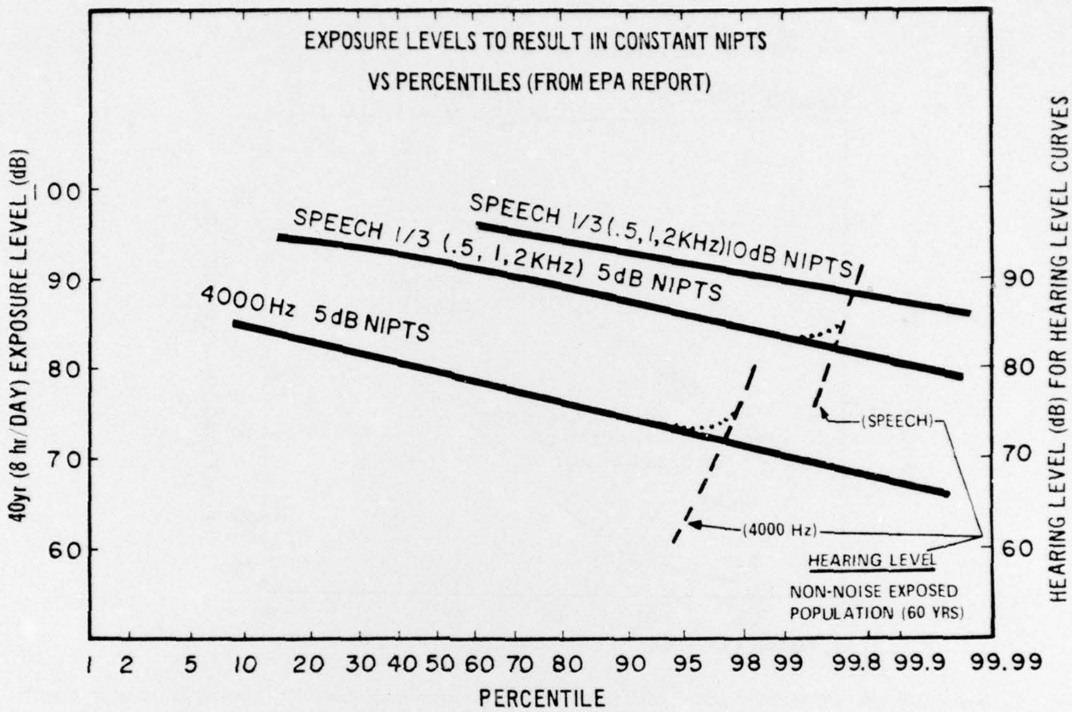

Fig. 5.—Full lines are curves of constant NIPTS as a function of 40-yr exposure level (lefthand scale) and population percentile; dashed lines represent hearing levels (righthand scale) by percentiles of a non noise-exposed 60 year old population. NIPTS curves must stay above and will merge with normal hearing level curves (dotted lines).[5]

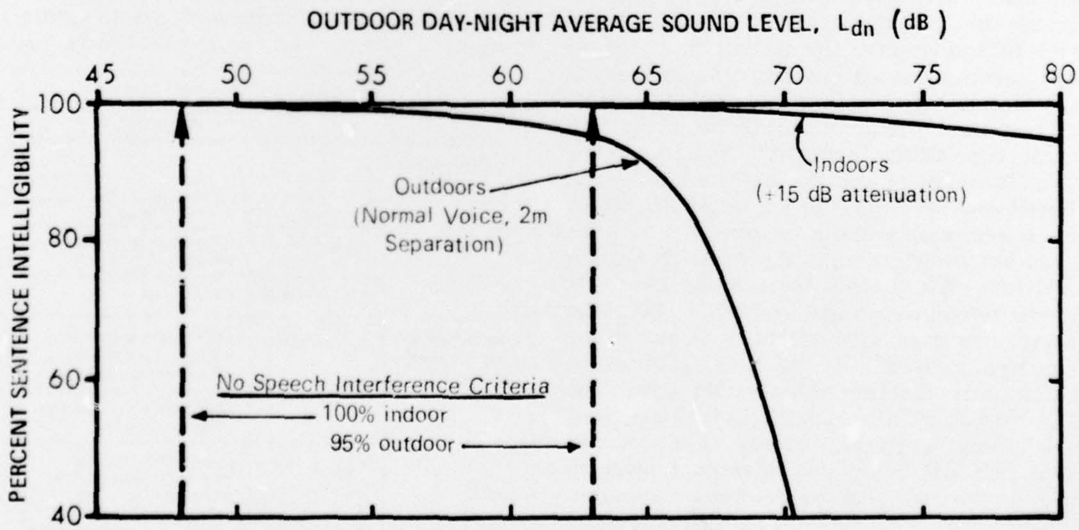

Fig. 6.—Minimum sentence intelligibility for normal voice as a function of the background day-night average noise level (L_{dn} is based on L_d+3). The criterion for "no speech interference" indoors in a typical living or bedroom with 300 sabins absorption is 100% sentence intelligibility achieved at an indoor $L_{eq} \leq 45$ dB; the outdoor criterion of 95% sentence intelligibility for normal voice conversation with speaker to listener distance of 2m is satisfied at $L_{eq} \leq 60$ dB. The indoor and outdoor criteria are satisfied according to the curves presented for an outdoor $L_{dn} \leq 63$ dB.

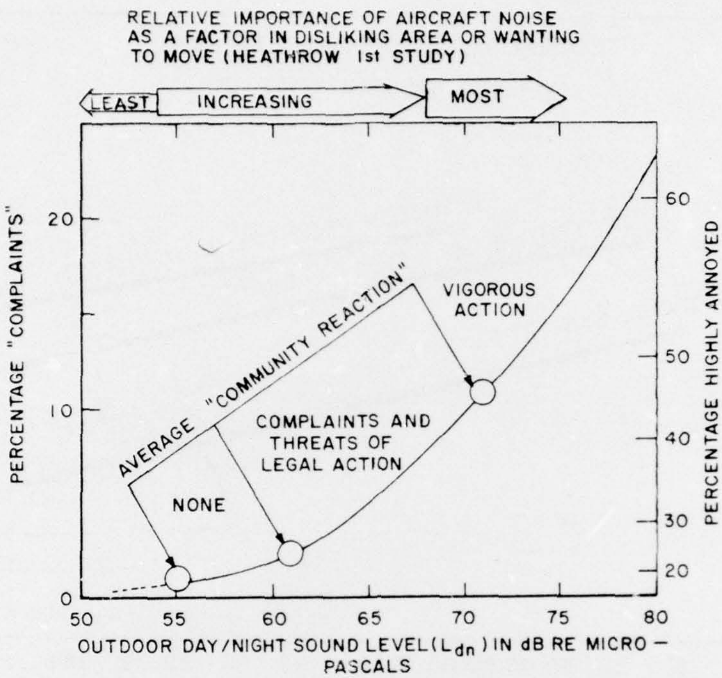

Fig. 7.—Summary of annoyance/complaint responses to interfering outdoor day-night sound levels. (Derived in ref. 5).

condensed results of all community noise studies[5,9] are shown in figure 7. The increase in annoyance and complaint behavior of individuals, the weight attached to the noisiness of an environment in making the decision to move away and the overall community response to the noise environment can all be expressed by one curve as a function of the day-night sound level. Based on these data an L_{dn} of 55 dB might be a reasonable limit, below which noise does not interfere significantly with human activities. Above this level more than 1% of the population might complain about the noise and over 17% might indicate to be "highly annoyed" by the noise. Concerted community reaction might start when the L_{dn} exceeds 60 dB. At an L_{dn} of 55 dB average indoor levels are approximately 40 dB, a level 5 dB below the identified level to prevent interference with indoor communication. An indoor L_{dn} of 40 dB is usually coupled with a nighttime level of 32 dB (open window), a level well consistent with the limited data on sleep interference.

It was this combined reasoning which led the EPA to identify an outdoor L_{dn} no greater than 55 dB in residential areas as the limit compatible with the protection of public health and welfare with an adequate margin of safety. Knowing the limits re-

TABLE 1.—*Summary of maximum noise levels identified requisite to protect public health and welfare.*

Effect	Level	Area
Hearing Loss	$L_{eq(8)} \leq 75$ dB	Occupational and educational settings
	$L_{eq(24)} \leq 70$ dB	All other areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(8)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

quired to protect against undue health effects, the EPA then identified the levels of environmental noise needed to protect public health and welfare in various areas, as required by the Noise Control Act. A summary of these limits is presented in Table 1.

Application

The uniform descriptor, coupled with the identified levels, allow for the first time a quantitative analysis of the cost involved and of the priorities to be assigned if worthwhile goals are to be achieved. The goal is the same for all types of noises, wherever and whenever they operate and whatever characteristic the noise source has: to reduce the adverse health effects of the noise. The contribution of individual noise sources can be calculated, estimated, measured and monitored for individual areas as well as for a whole country, and the cost effectiveness of various alternatives can be evaluated with respect to source emission or aircraft certification standards, and with respect to highway or city planning. The day-night average sound level is also being proposed as the uniform descriptor for documenting and quantifying the environmental impact of noise caused by any action that would change the exposure of people to noise.

Use of the common descriptor allows us for the first time to appreciate the task at hand to reduce environmental noise below certain limits. Analysis of figure 4 indicated that for example in the US more than half a million people are living in an environment with an outdoor L_{dn} above 80 dB; 1.5% of the US population or 3 million people are exposed to an outdoor L_{dn} of 75 dB and over 15% are exposed to levels over 65 dB. To have the whole US population live in noise environments that do not exceed an L_{dn} of 60 dB, would necessitate changing the noise environment and probably the overall lifestyle of approximately 30% of the US population! These figures make it clear that the limits identified in Table 1 are long range goals and that for some time to come the noise levels associated with our industrialized lifestyle will have an effect on public health and welfare. To make this conclusion not too depressing, it must be kept in mind that the benefits derived from the various operations that create the environmental noise were not considered when these limit levels were identified. In many cases deleting those benefits would have a more severe effect on public health than does the noise connected with the benefit. However, too much consolation from this argument is not justified. There is good reason to conclude that by proper overall long range city planning and by emission standards and exposure controls, environmental noise levels at places where people live and work can be lowered to the identified goals. For working toward such a goal a uniform descriptor such as the one discussed is absolutely essential.

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